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THE COMPARISON OF ROAD CAPACITY OF GREENSHIELD MODEL, GREENBERG MODEL AND UNDERWOOD MODEL TOWARD MKJI 1997 CALCULATION ON THE JENDRAL SUDIRMAN ROAD, BATANG

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ABSTRACT

Jendral Sudirman road is one of the streets in Batang Regency which has function as primary artery and it has main access to connect vital locations. It makes Jendral Sudirman road has several transportation problems. In the planning, design and establishment of various transportation system policies, traffic flow theory of movement has very important role. To facilitate the application of traffic flow theory of movement used a mathematical approach which was used to analyze the phenomenon that took place in the traffic flow. One of approach ways to comprehend the traffic behavior was by verifying it into mathematical and graphics relationships with observing to the relationship among the speed (S), density (D) and volume (V) traffic.

The objective of this study was to determine traffic flow characteristics on Jendral Sudirman Road consisting of three (3) main parameters such as volume, speed and density by using mathematical models included Greenshield, Greenberg and Underwood Model. In addition, this study also aimed to determine the results of a comparison of one of the chosen model with the road capacity calculation based on MKJI 1997.

Based on the data analysis by using Greenshield model, it was known that the characteristics of the traffic on Jendral Sudirman road values obtained free flow speed (Sf)= 45.53 km/h, density jam (Dj)= 38.31 unit/km and maximum volume or road capacity(Vmax)= 1774.25 unit/hour. The estimation result of model was calculated using Greenshield model and estimation capacity calculations of MKJI 1997 had a difference about 15.49%. This could be evidence that generalize the use of manual book as MKJI 1997 in estimating the value of a certain road location capacity without researching driver behavior, vehicle characteristics and the environment of the road would be at risk in the capacity estimation results obtained. Therefore, the use of existing guidelines such as the 1997 MKJI needs carefulness in assessing the environmental condition of the road and traffic characteristics.

Keywords : TrafficCharacteristic, Volume, Speed, Density, Greenshield, Greenberg, Underwood

1. Introduction

Jendral Sudirman Road is one of the streets in Batang which has function as primary artery and it has main access to connect vital locations. The land use in Jendral Sudirman Road consists of service centers, activity centers, government centers, and shopping centers. It makes Jendral Sudirman Road has several transportation problems, including traffic characteristic problem that causes road service decreases and traffic performance is not optimal.

In planning, designing and establishment various transportation system policies, the theory of traffic flow has very important role. To facilitate the application of traffic flow theory of movement is used a mathematical approach which is used to analyze the phenomenon that took place in the traffic flow. One of approach ways to comprehend the traffic behavior was by verifying it into mathematical and graphics relationships. Based on the explanation above, then the objective of the study is:

1. To find out the realationships among Volume, Speed , and Density by using Greenshield Model, Greenberg Model and Underwood Model on Jendral Sudirman Road, Batang;
2. To find out the comparison result of road capacity calculation between model result and road capacity calculation based on Manual Kapasitas Jalan Indonesia (MKJI 1997);
3. To give recommendation road capacity calculation model that is the most appropriate with the Jendral Sudirman Road Caharceteristic where the location is in Batang.

While the contribution of this study is expected to be an input in the estimation of road capacity calculations to assess the performance of a road so that the service level of a road that is obtained can be more representative and accurate.

2. Literature Riview

2.1 Traffic Flow Characteristic

Traffic flow is a unique interaction among the driver, vehicle, and road. There is not same traffic flow even in similar circumstances. therefore the current road always has many variations

2.2 Traffic Volume

Volume is used to measure the amount of traffic flow. The traffic volume shows the number of vehicles that cross in one observation point in one unit of time (days, hours, and minutes) (Sukirman 1994: 42). The important thing in road design and traffic control is the

volume at rush hours which is usually 8-10% of the total daily flow or 2 to 2.5 times from the average daily volume. The two peak rush hour on working days occur at the peak of the morning and evening which evening peak hours tend to be more prominent. (Hobbs 1995: 67).

2.3 Speed

Speed is a quantity that shows the distance traveled by a vehicle divided by travel time. A good road plan must be based on the speed chosen from the belief that the speed is in accordance with the expected road conditions and functions. Hobbs, F.D. (1995: 86) states that, speed is generally divided:

1. *Spot speed* is the vehicle speed at a measured time from a determined location
2. *Running speed* is the average vehicle speed on a road when the vehicle is moving and is obtained by dividing the length of the road and then it is divided by the length of time the vehicle moves through the road.
3. *Journey speed* is the effective speed of a vehicle that is traveling between two places, and is the distance between two places divided by the length of time for the vehicle to complete the journey between the two places, with this length of time including any time stops that is caused by traffic barrier.

2.4 Density

Density is a combination of speed and traffic volume (unit) and also measure the total of vehicle travel time needed to take each road segment.

2.5 The Relationship Among Volume (V), Speed (S), and Density (D)

In the characteristics of traffic flow, there are 3 main parameters used to analyze the traffic flow, they are Volume (V), Speed (S), and Density (D). From the three parameters above, we analyze the mathematical relationship using the model. The model that is used to analyze the relationship of the three parameters are the Greenshields Model, Greenberg Model, and Underwood Model.

In a study, the selection of the Greenshield model is quite easy because this model is simple and can explain the trends that are obtained from observing the traffic flows. Whereas for other methods which have weaknesses, namely for the Greenberg model it has the disadvantage that this model is invalid for small densities because at a density close to zero, the speed value is very large (infinity), while for the Underwood model

where this model is invalid for high density, because speed never reaches zero when high density.

2.5.1 Greenshield Model

This model is the earliest model that is recorded in an effort to observe the characteristics of traffic flow on the highway. In 1934, Greenshield conducted a study on the road outside of Ohio, where traffic conditions required because uninterrupted and moving freely. Greenshield gets the result that the relationship between speed and density is linear.

The linear relationship between speed and density is a popular relationship in reviewing traffic flow movements, considering the simplest relationship function therefore that it is easy to implement. This model can be shown:

$S = Sf – (Sf/Dj)\ D$ ..... (1)

S = Average Speed (km/hour)
Sf = Free Flow Speed (km/hour)
D = Average Density (unit/km)
Dj = Density jam (unit/km)

If S= V/D is distributed into formula (1), then it is obtained the relationship between Volume (V) and the density (D) as follows:

$V/D = Sf – (Sf / Dj)\ D$

$V = Sf.D – (Sf / Dj)D^2$ .....(2)

If D= V/S is distributed into formula (2), then it is obtained the relationship between Volume (V) and Speed (S) as follows:

$S = Sf – (Sf /Dj)V/S$

$V = Dj.S – (Dj /Sf)\ S^2$ .....(3)

Maximum volume occurs while the value of density optimum (Do) that is if first derivative of the formula (2) is equal zero.

$\frac{V}{D} = Sf – 2.D\ (Sf/Dj) = 0$

$D = \frac{D}{2}$…….....(4)

If the value of Do is distributed into formula (2) then, Volume Maximum (Vmax) can be obtained, therefore:

$Vmax = \frac{S \quad .D}{4}$.....(5)

Dj = Density jam (unit/km)
Sf = Free Flow Speed (km/hour)
Vmaks = Capacity (unit/hour).

2.5.2 Greenberg Model

This model assumes that traffic flow has similarities with fluid flows. Greenberg conducted a study in 1959 that was held in the tunnel and analyzed the relationship between speed and density using the continuity equation and movement of liquid objects. By this assumption, Greenberg obtained a relationship between Speed and Density in the form of logarithms.

S = So. ln (Dj /D) .....(6)

So = Speed Optimum (km/hour)

If S = V/D is distributed into formula (6) then will be obtained a model of relationship between Volume (V) and Speed (S) of ttaffic flow as the formula (10).

V/D = So. ln (Dj /D)

V = So. D .ln (Dj/D) .....(7)

If D = V/S is distributed into formula (6) then will be obtained a model of relationship between volume (V) and speed (S).

$S = So.ln\ (\frac{D}{V/S})$

V = Dj .S .e-(S/So) .....(8)

Maximum flow occurs when the value of density optimum (Do) is reached, that is if the first derivative of formula (7) is equal zero, namely:

$\frac{V}{D}$= So . In (Dj/D) – So = 0

D = Do = Dj / e ……...(9)

Then if the value of Do = Dj/e is distributed into formula (8) therefore, it will be obtained the maximum volume value, so that:

Vmaks = So. Do ...…….(10)

2.5.3 Underwood Model

The Underwood model suggests that the relationship between speed and density of traffic flows follow the exponential function by formula below:

S = Sf .e (D/Do) .....(11)

By changing the formula (11) into linear form Y= a + bX,

ln S = ln Sf – D/ Do .....(12)

Y = ln S
a = ln Sf
b = - 1/Do

If V = S x D is distributed into formula (9) then will be obtained a model of relationship between volume and Traffic flow density, namely:

$V/D = Sf .e^{-(D/Do)}$

$V = Sf .D .e^{-(D/Do)}$ .....(13)

If D = V/S is distributed into formula (9) then, obtained a model relationship between Volume and Traffic Flow Speed, as follows:

$S = Sf .e^{-((V/S)/Do)}$

V = Do.S.ln (Sf /S) .....(14)

When the value of density optimum (Do) is reached, then the Volume Maximum (Vmax) also occurs, so, it is mathematically obtained that the condition of Vmax. if the first derivative formula (14) is equal zero, therefore:

Vmax = Sf. Do/e .....(15)

2.6 Road Capacity

Road capacity is the road performance to receive the flow or ideal traffic volume in a certain time unit, it is stated in the number of vehicles that pass certain road section in one hour (vehicle/hour) or by considering various types of vehicles that pass in a road are used a passenger car as a vehicle unit in calculating the capacity. Therefore, the capacity uses unit / hour.

In a study for analyzing the capacity of this road, using formulas based on guidelines in the *Manual Kapasitas Jalan Indonesia* (MKJI) and calculating basic capacity (Co) which becomes the standard of each lane of road, then it is multiplied by adjustment factors (F) that is consist of road width adjustment factors, side barriers, and city size. For capacity calculations are obtained by using the equation:

$C = C_O x\ FC_W x\ FC_{SP} x\ FC_{SF} x\ FCcs$

C = Road Capacity (unit/hour)
CO = Basic Capacity(unit/hour)
FC_W = Factor of Road Width Adjustment
FCSP = Factor of Direction Separation Adjustment
FC_{SF} = Factor of Road Side Barrier Adjustment
FCcs = Factor of City Size Adjustment

2.7 Linear Regression Test

Linear regression analysis is also a statistical method that can be used to learn the relationship between the characteristic of the problem that is being investigated. The linear regression analysis model can model the connection between 2 (two) modifier or more. In this model there is a non-independent modifier (y) that has a functional relationship with one or more free modifier (Xi). In the simplest case, the relationship can generally be stated in the *Ofyar Z tamin* equation, as follows:

$Y = a + bx$

Y = non-free Modifier
x = Free Modifier
a = intercept or regression constant
b = regression coefficient

3. Methodology

3.1 Research Location

This study was conducted on the Jendral Sudirman Road Batang where the study area was 50 meters where had boundary from *Jembatan Penyeberangan Orang* (JPO) until Bank BTN Batang Branch Office.

3.2 Data Obtainined Method

3.2.1 Traffic Volume

The Survey of traffic volume calculation was intended to find out the total of traffic volume and moving vehicles population in a research location. This survey was conducted by calculating the composition of vehicles that passed the Jendral Sudirman Road, Batang in a certain time. Data collection of traffic volume and speed data were obtained on Monday, March 4, 2019 for 12 hours (6:00 to 18:00 WIB) by recording video.

3.2.2 Vehicle Speed

The survey of Vehicle traffic speed was conducted with the aim of identifying the average speed of local traffic. This survey was conducted manually (did not use a survey tool) that was by observing the video recordings that had been obtained from the survey results that had determined the point or observation distance. Then, it would be conducted a calculation of speed by comparing between travel time and distance (50 m).

3.3 Data Analysis Method

3.3.1 Model Analysis

In the characteristic of traffic flow there were 3 main parameters that were used to analyze the traffic flow, such as volume (V), speed (S), and density (D), from the three parameter, we analyzed the mathematical relationship using the model. The model that would be used to analyze the relationship of the three parameters was the Greenshields

Model, Greenberg Model, and Underwood Model. Then, we choose one model that was appropriate to the characteristics of the scope of the study.

3.3.2 Road Capacity Analysis

For the comparison calculation of road capacity, the study was conducted by one of the selected models that were appropriate with the characteristics of Jendral Sudirman Road, Batang and it was compared with the calculation of road capacity based on the *Manual Kapasitas Jalan Indonesia (MKJI 1997).*

4. Discussion And Result

4.2.1 Model Analysis

To decide mathematical model relationship among Volume (V), Speed (S) and Density (D), we might firstly estimate the model parameters by using regression analysisi technique:

Table 1. Parameter of Model

Parameter	Model		
	Greenshield	**Greenberg**	**Underwood**
a	52,04	68,36	3,75
b	-0,74	-10,17	-0,0016
Sf	52,04	-	42,49
So	26,02	10,17	16,99
Do 2 Directions	35,10	414,06	618,80
Dj 2 Directions	70,20	828,12	-

Source : Analysis Result, 2019

The following was a modeling structure of the relationship among Volume (V), Speed (S) and Density (D) that is obtained from filling the model parameter values:

Table 2. Structure of Model

Model	Field Model
Greenshield	$S = 52{,}05 – (0{,}741)D$
	$V = 52{,}05\ D – (0{,}741)\ D^2$
	$V = 70{,}207\ S – (0{,}741)\ S^2$
Greenberg	$S = 68{,}361 – 10{,}17\ InD$
	$V = 68{,}361\ D – 10{,}17\ D\ InD$
	$V = 828{,}127.\ exp(-10{,}17\ S)$
Underwood	$S = 42{,}49\ x\ exp(-0{,}0016\ D)$
	$V = 42{,}49\ D\ x\ exp(-0{,}0016\ D)$
	$V = 618{,}802\ S\ .\ In(42{,}49/S)$

Source : Analysis Result, 2019

4.2.2 Model Statistical Test

Model statistical tests were conducted to determine whether the model that was obtained required statistical requirements. If the yielded value of F (count) and t (count) were smaller than the value of F (table) and t (table). Therefore, the model was statistically rejected.

Table 3. Result of Statistical Model Test

Parameter	Greenshield Model	Greenberg Model	Underwood Model
a	52,05	68,36	3,75
b	-0,74	-10,17	-0,0016
r^2	0,89	0,963	0,301
F	373,117	1,202	19,82
t	19,316	-34,673	-4,465

Source : Analysis Result, 2019

If the value of F (count) and t (count) that was yielded was smaller than the value of F (table) and t (table), the model was statistically rejected. For two-sides testing on the Greenberg Model, the value of F (count) was smaller than the value of F (table). It meant that the model was not good. It described the significant influence between independent variables and unindependent variables that formed the model at the study location. For the Greenshield Model and Underwood Model, the value of F (count) and t (count) were bigger than the value of F (table) and t (table), thus for the two models, the vehicle density could affect the vehicle speed so that it was statistically concluded that the formed model can be accepted.

4.2.3 Model Selection Analysis

The best model was a model that could describe reality that was a model which independent variables could significantly explain unindependent variables. There were several criterias for selecting the best model, such as criteria based on statistical analysis and reasonable criteria. The following step was ways of choosing a model that could be used in the study location:

1. Determination coefficient value (r^2)

   The Value of determination coefficient (r2). The three continued models from the highest were Greenberg Model, Greenshield Model and Underwood Model;

2. Significance Test

   Based on the results of the model statistical test, it could be known that the relationship among traffic flow variables on all models was very significant to influence each other.

It could be known from the value of F (count) and t (Count) was bigger than F (table) and t (table).

3. Free Flow Speed Value (Sf)

   The speed value that was taken from the three models was the highest. Because the higher of the free flow speed value meant that the value was getting closer to the actual condition. Based on the results of the previous analysis, it was found that the free flow speed was the Greenshields Model, Underwood Model and Greenberg Model.

4. Density jam Value (Dj)

   The best Density jam (Dj) value was the value that was the closest to field conditions. The Density jam (Dj) value of field conditions was estimated about between 185 - 250 vehicles/mile or 120 - 160 vehicles/km (May, AD1990). Based on the Density jam (Dj) values of several models, the closest model for density Jam (Dj) was Greenshield Model, Greenberg Model and Underwood Model.

5. Capacity Value

   The common empirical capacity value for road type 4/2 UD was around 3800 unit/hour (MKJI 1997). The results of road capacity calculation in the Greenshield Model Vmax= 3,654,088 unit/hour, the Greenberg Model Vmax= 4212,748 unit/hour and the Underwood Model Vmax= 9,672.645unit/hour.

   From the five criterias above, the Relationship model among Speed (S) - Density (D) and Volume (V) that was appropriate for the study location was the Greenshield Model.From the structure of the model, it could be known that some characteristics of the traffic flow at the study location, namely free flow speed (Sf)= 52,043km/hour, density Jam that occured (Dj) = 70,207 pcu/km and maximum volume/road capacity (Vmax)= 3,654,088 unit/hour.

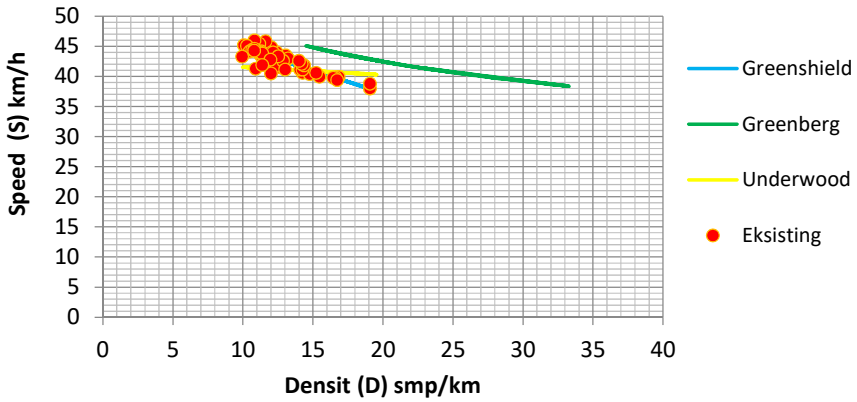

Figure 1 Graph of model relationship among Speed (S) and Density (D) Greenshield Model, Greenberg Model dan Underwood Model

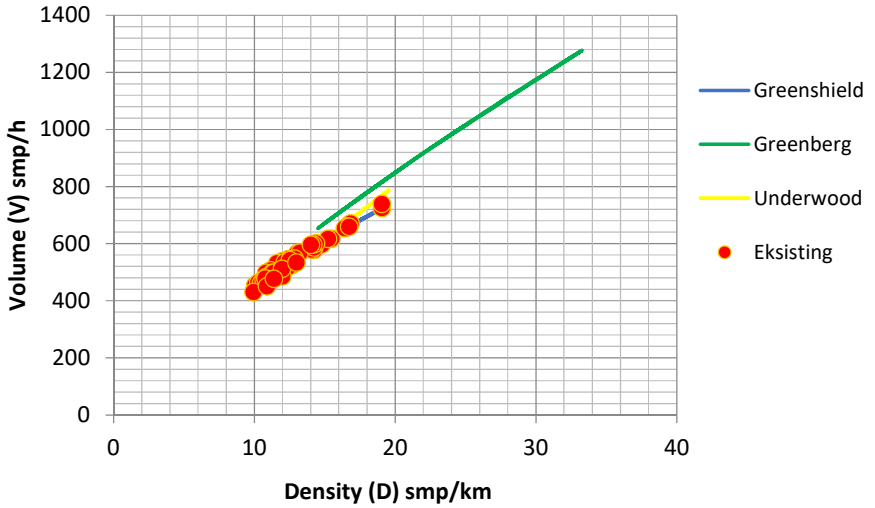

Figure 2. Graph of model relationship among Volume (V) and Density (D) Greenshield Model, Greenberg Model dan Underwood Model

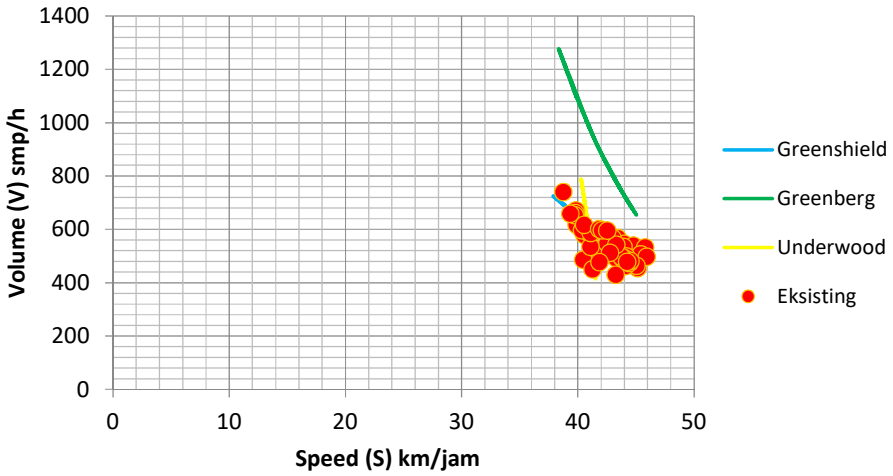

Figure 3. Graph of model relationship among Volume (V) and Speed (S) Greenshield Model, Greenberg Model dan Underwood Model

4.2.4 Road Capacity Analysis

The estimation of road capacity (C) was based on *Manual Kapasitas Jalan Indonesia (MKJI 1997)* was:

C = Co x FCw x FCsp x FCsf x FCcs

C = 3800 x 0,91 x 1 x 0,95 x 0,94

C = 3.087,994 unit/hour (Total = 2 Directions)

While the estimation of Road Capacity (C) was based on the results of the selected model, namely the Greenshield Model Vmax = 3,654,088 unit/hour. Thus it could be known that the calculation of road capacity that was obtained from the results of model estimation which was calculated using the Greenshield Model and the calculation of the estimated capacity of MKJI 1997 had difference about 15.49%.

5. CONCLUSION

5.1 Conclusion

Based on the analysis and the discussion, it is obtained some conclusion such as:

1. The relationships among Volume (V), Speed (S) dan Density (D) by calculating some mathematical model, as follows:

Model	The Structure of Model
Greenshield	$S = 52,05 – (0,741)D$
	$V = 52,05\ D – (0,741)\ D^2$
	$V = 70,207\ S – (0,741)\ S^2$
Greenberg	$S = 68,361 – 10,17\ InD$
	$V = 68,361\ D – 10,17\ D\ InD$
	$V = 828,127.\ exp(-10,17\ S)$
Underwood	$S = 42,49\ x\ exp(-0,0016\ D)$
	$V = 42,49\ D\ x\ exp(-0,0016\ D)$
	$V = 618,802\ S\ .\ In(42,49/S)$

2. The result of road capacity Calculation was based on the model estimation result, such as:
   - Greenshield Model, Vmax = 3.654,088 unit/hour;
   - Greenberg Model, Vmax = 4.212,748 unit/hour;
   - Underwood Model,Vmax = 9.672,645 unit/hour;
   - MKJI 1997, Vmax = 3.087,994 unit/hour.

   Thus, it could be known that the calculation of road capacity was obtained from the estimation of the selected model, namely the Greenshield Model and the results of road capacity estimation based on MKJI 1997 had a difference about 15.49%. These differences proven that there was not a location of a road that had same traffic characteristics.
3. The road capacity calculation model that was most appropriate with the traffic characteristics on the Jendral Sudirman Road in Batang was the Greenshield Model with the following traffic characteristics, namely free flow speed (Sf) = 52,043

km/hour, Density Jam that occured (Dj) = 70,207 pcu/km and Volume Maximum or road capacity (Vmax)= 3,654,088 unit / hour.

5.2 Suggestion

The suggestions of this study are:

1. The use of existing guidelines such as *Manual Kapasitas Jalan Indonesia (MKJI 1997)* requires carefulness in assessing the environmental conditions of the road. Because there is no road section that has same traffic characteristics even though the environmental conditions are very similar so every estimations of road performance. For this reason, the researcher must know the road conditions.
2. We need to look for other factors that affect the traffic flow, speed and density on the Jendral Sudirman Road in Batang;
3. For further research, it is necessary to analyze some models that is reviewed from several other factors, including side barriers, characteristics and behavior of road users, vehicle characteristics and environmental conditions of the road to find out the calculation of road capacity that is closer to the existing conditions on the road which will be examined.

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